the force sensors to determine the actual coordinate where the touch force was applied. The software transfers the calculated coordinates to the device's operating system.

[0029] Presently most commercial force sensors use piezoresistive materials to detect applied force. While most commercially available piezoresistive force sensors are highly accurate, they typically are not very durable and are large and expensive with only a few available component suppliers globally. There are alternative force sensors available, such as "force sensitive resistors" or FSR's, which are smaller, lower in cost and more readily available. Examples of FSRs are shown in U.S. Pat. Nos. 4,739,299, 4,489,302, 4,451,714, 4,315,238, 4,314,228, 4,314,227 and 4,306,480. A benefit of using integrated FSR sensors is that the voltage output is typically ten times higher then the voltage output for a piezo-resistive force sensor. This higher voltage output eliminates the need for additional analog signal amplification, thereby further reducing both required board space as well as component costs. The mechanical design is further simplified by use of the FSR sensor since these sensors do not need to be protected against overpressure, whereas a typical piezo resistive sensor does. Unfortunately FSR sensors have a much narrower range of sensitivity. In addition, there are also new, not yet commercialized, force sensor materials that are based on nano technology. The early indications from activities in this area are that the nano technology based sensors will be similar to FSR sensors in terms of low per unit cost, small size, yet will require similar added performance compensation and error correction.

[0030] Two embodiments of FSR sensors are represented in FIG. **2**. These sensors are typically made up of two plans of conductive materials **24** in sensor **20** or conductive traces in sensor **21** that are "connected" through FSR material. The characteristics of the FSR material are that it remains non-conductive until a force is applied. When a force is applied, the resistance in the material decreases as the applied force increases.

[0031] An example of such resistance-force relationship for a FSR sensor is illustrated in FIG. **3**. The nature of this resistance-force relationship can be controlled through the design of the FSR material and the sensor, so that the sensor may have its sensitivity optimized for a specific force range. As seen in FIG. **3** the sensor produces a useless result for forces less then 70 grams, but has a very high sensitivity up to 200 grams. The sensitivity is reduced, but still significant in the 200 to 450 gram range, where the resistance level begins to flatten towards 3 kOhm.

[0032] Referring back to FIG. **2**, also illustrated (at right) is a typical electrical connection, where an FSR sensor is typically connected as seen at **22** with a matching pull-down resistor, here a 3 kOhm resister. The sensor reading, Vout, is a function of the supply voltage, Vdc, and the resistance of the FSR sensor at a given applied force. This relationship is illustrated in FIG. **4**, were it is demonstrated how the sensor reading (Vout) is increasing as the resistance in the FSR material decreases with the increase in the applied force. It should be noted that the force-Vout relationship would be very different for a piezo resistive sensor, where the relationship is linear from 0 gram force up through its operating range.

[0033] FIG. **5** illustrates the performance difference between different sample FSR sensors with the same design. It can be seen from FIG. **5** that the individual resistance value of one sensor sample differs significantly compared to a second sample, even within the same production batch. A third characteristic of the typical FSR sensor is that they are, unlike the Wheatstone bridge based piezo resistive force sensors, temperature dependent.

[0034] FIG. **6** illustrates how the resistance—force relationship changes for the same sensor measured under identical conditions, but at different temperature levels. These above-described characteristics make it difficult to design a differential-pressure touch pad assembly based on FSR technology. Nevertheless, the present inventors have devised a software compensation approach that allows the use of small and low-cost force sensing sensors, such as FSR sensors.

[0035] It would, therefore, be greatly advantageous to provide a force sensing technology which overcomes some of the above deficiencies of the prior art.

SUMMARY OF THE INVENTION

[0036] Accordingly, it is an object of the present invention to optimize an alternative force sensor technology in order to provide a low-cost pressure sensitive touch sensitive display solution suitable for manufacturers of electronic devices such as POS, ATMs and terminals and, specifically, portable electronic devices such as cell phones, cameras and PDA and other mobile computing devices.

[0037] This and other objects are accomplished herein by a force sensing resistor able to serve as a replacement for the high performing piezo resistive force sensors. In order to replace the piezo resistive force sensor, the present force sensing resistor is supported by software that includes compensation and calibration algorithms and modules.

[0038] The force sensing resistor based touch screen assembly generally comprises either a floating lens suspended over the display, or as an alternative a floating display module. The floating lens, or floating display module, rests on or includes a plurality (n=3 . . . m) of differentially-mounted force sensing resistors. The pressure sensors are differentially positioned along an x- and y-axis for registering a pressure z from a touch to the lens at each of the positions, to provide a corresponding plurality of data sets (x**1**-m, y**1**-m, z**1**-m). The sensors are then electrically connected through basic electronic components on flex film or PCB via an A/D converter, where the analog sensor reading is converted to a digital signal, to either a dedicated processing unit (such as a microcontroller) or the main processor where the touch screen related software is executed.

[0039] This control software provides the precision and accuracy of the system through a number of functional modules, including filtering, voltage conversion, sensor calibration, sensor reading linearization, auto calibration, positioning determination and finally end-user and mechanical calibration.

[0040] The positioning determination of a force sensing resistor based touch screen, without any additional compensation or calibration, is typically running with an average positioning error of 20%-50%, which would more or less render such system useless. The added compensation and calibration algorithms will bring the system accuracy up to an average positioning error between 0 and 5%, depending on size, electrical components and mechanical design, which is on par with a piezo resistive based touch screen system.